ECF-200UP1-17-0010
Revision 0

200-UP-1 Leapfrog Models of U Plant Uranium and Technetium-99 Plumes Fall 2015

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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ADD ROW

Environmental Calculation File 200UP1-17-0010, Rev. 0

200-UP-1 Leapfrog Models of U Plant Uranium and Technetium-99 Plumes Fall 2015

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Terms

CHPRC	CH2M HILL Plateau Remediation Company
COI	contaminant of interest
CY2015	calendar year 2015
ECF	environmental calculation file
EMMA	Environmental Modeling Management Archive
HEIS	Hanford Environmental Information System
HISI	Hanford Information System Inventory
m	meter
OU	operable units
NAVD88	North American Vertical Datum of 1988
pCi/L	picocuries per liter
Tc-99	technecium-99
ug/L	micrograms per liter

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1 Purpose

The purpose of this environmental calculation file (ECF) is to present the methodology, input data, and results used to delineate three-dimensional groundwater plumes for two contaminants of interest (COIs) – uranium and technecium-99 (Tc-99) – in the 200-UP-1 and 200-ZP-1 operable units (OUs). The three-dimensional interpolation was carried out in the Leapfrog-Geo®[1] geologic modeling platform, which includes an interpolation engine for analyzing and visualizing three-dimensional data.

Input data were derived from two-dimensional groundwater plumes developed in ECF-HANFORD-16-0061, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2015 (CY2015) Hanford Site Groundwater Monitoring Report*, depth-discrete groundwater samples, and samples collected from existing water wells. Data from the two-dimensional plumes were placed at elevations corresponding to the March 2015 water table, depth-discrete sample data were placed at the elevation of their collection depth, and groundwater well sample data were placed at elevations dictated by the relative positions of the well screen and the March 2015 water table. Groundwater sample data were used to a greater extent for the Tc-99 plumes than for the uranium plumes, where the main plume of interest was sufficiently represented by depth-discrete data. All interpolated plumes were reviewed by project scientists, and effort was made to incorporate site-specific expertise in the delineation of these plumes.

[1] Leapfrog Geo is a registered trademark of ARANZ Geo Limited of Christchurch, New Zealand.

2 Methodology

The three-dimensional interpolation was conducted following the general methodology described in the subsections below. All digital files discussed in the text are stored in the Environmental Modeling Management Archive (EMMA) indexed to this ECF number (ECF-200UP1-17-0010, Rev. 0).

2.1 Input Data Processing

1. Two essential reference surfaces used in the development of the groundwater plumes are the March 2015 water table and the surface topography, both in the form of numerical grids (herein referred to as rasters). Values from these rasters were used to determine elevations of input data points for three-dimensional interpolation. The original water table raster, *2015wtbp.asc* (100-meter [m] resolution; DOE/RL-2016-09), and the original high-resolution Lidar topography raster, *HSWG_topo_new.tif* (0.5-m resolution; Aero-Metric LiDAR, 2008), were reduced down to the study area as shown in Figures 1a and 1b. These subset rasters, *2015wtbp_subset_to_UPlantAOI.tif* and *HSWG_topo_new_subset_to_UPlantAOI.tif*, are included with this ECF as digital files.
   a. Note that, while the spatial resolution of the original surfaces was preserved when the grids were downsized, the locations of cell boundaries shifted somewhat, leading to recalculation of cell values based on the values in the original rasters. Extracted cell values at a point from the original surfaces are very likely to differ by a small amount from extracted cell values at the same point using the subset rasters.

2. The two-dimensional representations of the uranium and Tc-99 plumes for 2015 developed in HANFORD-16-0061 were received as raster layers *U_2015_Lo_5m* and *Tc99_2015_5m* in the geodatabase *CY2015_5M_Plumes.gdb* (DOE/RL-2016-09). Uranium concentrations are expressed in units of micrograms per liter (ug/L), and Tc-99 concentrations are expressed in units of picocuries per liter (pCi/L). These were reduced down to the study area as shown in Figures 2a and 2b. The subset raster file names are *Uranium_200-UP-1_subset.tif* and *Tc99_200-UP-1_subset.tif*.
   a. The raster cell values were converted to points distributed at their original resolution of 5 meters using the 'Raster to Point' tool in ArcGIS®[2] 10.3.1. This provides X- and Y-coordinates for all points within the raster, as well as the numerical concentration value at each point.
   b. Z-coordinates for each point were derived from the two-dimensional rasters by assigning them elevations from the water table raster *2015wtbp_subset_to_UPlantAOI.tif* described previously. This was done using the ArcGIS Spatial Analyst add-on tool 'Extract Multi Values to Points.'
   c. Data for these points (X, Y, Z, Concentration) were extracted to CSV files and combined with other input data as described later in this document.

3. U-Plant depth-discrete data for total uranium and uranium-238 are listed in file *U_Plant_DepthDiscreteData.xlsx*, and a similar data set for Tc-99 is listed in file *U_Plant_DepthDiscreteData_Tc-99.xlsx*. Because some of these data are several years old, the data sets were reviewed for representativeness to current conditions by comparing to recent sample results from the wells. Data deemed no longer representative were excluded from the plume interpolations. No data were excluded for uranium, but the depth-discrete data for several wells were excluded from the Tc-99 data set, as documented in *U_Plant_DepthDiscreteData_Tc-99.xlsx*. This was because Tc-99 is more mobile than uranium, and therefore the older sample results have gone out-of-date faster than have the uranium data. These original data sets often included multiple samples for a discrete X, Y, Z location, which can lead to biased representation of data points and is invalid for input into

[2] ArcGIS is a registered trademark of ESRI, Redlands, California.

Leapfrog. A map view of the locations of the depth-discrete samples used in the interpolations of uranium and Tc-99 is given in Figures 3a and 3b.

a. For the uranium plumes, sample data for both uranium and uranium-238 were used.
    i. Within tabs 'Uranium_raw' and 'Uranium238_raw' of spreadsheet *WC_00_U_Plant_discrete_depth_111616.xlsx*, a single representative value for each X, Y, Z location was chosen by process of elimination. Redundant values were removed, and favor was given to sample results with a higher concentration value or more recent sampling date. Reasons for exclusion of omitted sample results are preserved within these spreadsheet tabs.
    ii. Uranium and uranium-238 data were combined within tab 'U_U238_combining' of the same spreadsheet. In several instances, both uranium and uranium-238 were sampled at the same location. In these cases, the result with a higher concentration value was preserved for use in the interpolation.
    iii. The final values to be used for each X, Y, Z location are organized in tab 'U_U238_Combined' of the spreadsheet and were copied to a CSV file for use as Leapfrog inputs.

b. A similar process was carried out for the Tc-99 depth-discrete data in spreadsheets *WC_02_Tc99_ DepthDiscrete_121416.xlsx* and *C_03_Tc99_DepthDiscrete_121416.xlsx*.
    i. Duplicate values were removed, higher concentration values were favored, and recent measurements were favored in the case of multiple samples at a location. Non-detects were assigned a value at their detection limit. In the case of multiple non-detects, the sample with the lowest detection limit was used. This was carried out in spreadsheet *WC_02_Tc99_DepthDiscrete_121416.xlsx*.
    ii. Further revisions were carried out in spreadsheet *WC_03_Tc99_DepthDiscrete_121416.xlsx* per discussions with the project scientist.
        1. Sample results for well 699-33-74 were scaled by 0.5 due to a decline in concentration in the screened well from 410 picocuries per liter (pCi/L) when the well was first sampled in 2008 after the depth-discrete samples were collected during drilling, and 204 pCi/L during May 2015.
        2. Data for well 299-W11-25B were omitted. Although there are no recent samples from this well (it was damaged during completion and decommissioned), the depth-discrete samples collected in 2005 were deemed out-of-date due to later operation of a nearby extraction well.
        3. Sample results for well 299-W22-91 were scaled by 0.22. This is an extraction well that has been operating since 2012 and concentrations in samples from the completed well have declined from 15,700 pCi/L in 2012 to 3,480 pCi/L in 2015 (78 percent).
        4. The value of the sample at elevation 71.078 (m NAVD88[3]) in well 299-W22-114 was changed from -5.25 pCi/L to zero.
    iii. The final values to be used for each X, Y, Z location are organized in tab 'Rev1_DD' of spreadsheet *WC_03_Tc99_DepthDiscrete_121416.xlsx*. These were copied to a CSV file for use as Leapfrog inputs.

4. Recent groundwater sample data from existing wells were used to augment the depth-discrete sample data sets. More data were used for the Tc-99 plumes because more of the depth-discrete data were deemed out-of-date compared to the uranium data. Use of recent sample results for uranium was limited to the area of elevated uranium concentrations at U Pond, where depth-discrete data were not

[3] All elevations in this ECF are in the North American Vertical Datum of 1988 (NAVD88).

available. A map view of the well locations used for development of the uranium and Tc-99 plumes are given in Figures 4a and 4b.

a. Well screen data used to inform placement of groundwater sample data for these plumes are included digitally in the spreadsheet Hanford_screens_rev1_010917.xlsx. This file is the result of combining well screen data used in a similar plume development effort documented in ECF-200UP1-14-0047, *Initial Groundwater Plume Development (Chromium, Tritium) to Support Fate and Transport Modeling for Remedial Design in the 200-UP-1 Groundwater Operable Unit*, with screen data for additional wells obtained from the Hanford Environmental Information System (HEIS) database. It was discovered that the well screen depths for 299-W23-19 in HEIS were in error; a correction is incorporated into this spreadsheet (the depths in HEIS were subsequently corrected).
b. Water well sample data used to create the 2-dimensional plumes in ECF-HANFORD-16-0061 were used as the recent groundwater sample concentration values. The concentration data for Tc-99 is in file *Technetium-99_unique.csv*, and concentration data for uranium is in file *Uranium_LO_unique.csv*.
c. Water table elevation and ground surface elevation values were determined for individual well locations using the rasters described previously and the ArcGIS Spatial Analyst tool 'Extract Multi Values to Points' tool.
d. Relevant data for Tc-99 were copied to spreadsheet *WC_01_Well_Sample_Data_122116.xlsx*, and the disposition of whether and how to represent groundwater sample data was determined.
   i. If depth-discrete data are available for a well, that is used in favor of well sample data.
   ii. Extraction wells with no depth-discrete data are omitted.
   iii. Soft data points (i.e., points added based on professional judgment rather than on actual measurements) used for generating the two-dimensional plume rasters and located inside plume raster footprints are omitted.
   iv. Soft data points located outside plume raster footprints are represented as a single point at the water table.
v. Where well sample data are used, the data are represented as one to three points at the well location:
   1. If the screen bottom is located above the water table, a single point is placed at the water table.
   2. If the screen bottom is below the water table but the screen top is above the water table, the saturated screen interval was represented as a point at the water table, a point at the well bottom, and at a point midway between.
   3. If the well screens are fully within the saturated zone, points are placed at the screen top elevation, screen bottom elevation, and a point midway between.
e. Sample data and well information for wells to be used in the Tc-99 interpolation were copied to a new spreadsheet *WC_02_Well_Sample_Data_122216.xlsx*. Data were formatted for Leapfrog input in this spreadsheet.
   i. Note that the correction to the screen elevation for well 299-W23-19 described in item 4a above was carried out in this spreadsheet and not earlier in the process.
f. Five water well samples were used in the interpolation of the uranium plumes, and these were only in the area near the smaller plume located at U Pond. Data for these wells were organized in spreadsheet *WC_00_Sample_Data_Uplant_Uranium_122216.xlsx.*

5. Control points were added at varying depths at a few locations where plume interpolation using only the data described above resulted in awkward or unrealistic geometries. A map view of the locations of these control points is given in Figures 5a and 5b. All control points were created by manually

placing points along a line connecting two existing data points and linearly varying the elevation and concentration of each point based on the elevation and concentration of the existing end point concentrations. That is, the concentration and elevation values of each control point were linearly interpolated between corresponding endpoint values based on distance along the line.

a. Distance along the line at point *i* was calculated from Northing and Easting coordinates as

$$Distance_i = \sqrt{(Easting_i - Easting_0)^2 + (Northing_i - Northing_0)^2}$$

Where

($Easting_0$, $Northing_0$) is the coordinate pair for the starting endpoint

b. The elevation of point *i* was calculated as

$$z_i = z_0 + \frac{(z_n - z_0) \cdot Distance_i}{Distance_n}$$

For

$$1 \le i \le n - 1$$

Where

z_n is the elevation of the endpoint at the end of the line

z_0 is the elevation of the endpoint at the beginning of the line

$Distance_n$ is the linear distance between endpoints ($Easting_0$, $Northing_0$) and ($Easting_n$, $Northing_n$)

c. The concentration of point *i* was calculated as

$$C_i = C_0 + \frac{(C_n - C_0) \cdot Distance_i}{Distance_n}$$

For

$$1 \le i \le n - 1$$

Where

C_n is the concentration of the endpoint at the end of the line

C_0 is the concentration of the endpoint at the beginning of the line

$Distance_n$ is the linear distance between endpoints ($Easting_0$, $Northing_0$) and ($Easting_n$, $Northing_n$)

d. A total of 9 control points are included in the interpolation of the uranium plumes. These are placed along a line connecting the depth-discrete measurement at 299-W19-49 (elev = 116.5 m) with 299-W19-115 (elev = 108.995 m) and along a line connecting 299-W19-49 (elev = 116.5 m) with 299-W19-46 (elev = 115.85 m). These were developed in spreadsheet *points_btw_299-W19_49_115_113016.xlsx*.

e. A total of 24 control points are included in the interpolation of the Tc-99 plumes. These are placed along a line connecting an input data point at well 299-W19-113 (elev = 121.39 m) with a point at well 299-W19-34A (elev = 113.34 m), a line connecting the same point at 299-W19-34A with a point at 299-W19-114 (elev = 110.07 m), a line connecting a point in 299-W22-116_mid (elev = 127.21 m) with a point in 299-W22-91 (elev = 124.24 m), and a line connecting the same point in 299-W22-91 with a point in well 299-W22-116_bot (elev = 121.87 m). These control points were developed in spreadsheet *tc99_CPs_122716.xlsx*.

6. Inputs for interpolation of the uranium plumes are combined in spreadsheet *uranium_inputs_combined_122716.xlsx*, and the input file to read into Leapfrog is saved out from this spreadsheet as *uranium_inputs_combined_04_122716.csv*.
   a. 9 control points from file points_btw_299-W19_49_115_113016.xlsx
   b. 23,407 points from 2D rasters positioned at water table from file *UP-1_U_rastervals_5m_spacing_112916.csv*
   c. 605 depth-discrete points from file UPlant_U_U238_Combined_DepthDiscrete_Nov2016.csv
   d. 12 water well sample data points from file WC_00_Sample_Data_Uplant_Uranium_122216.xlsx

7. Inputs for interpolation of the Tc-99 plumes are combined in spreadsheet *tc99_inputs_combined_04_122816.xlsx*, and the input file to read into Leapfrog is saved out from this spreadsheet as *tc99_inputs_combined_04_rev1_010917.csv*.
   a. 24 control points from file *tc99_CPs_122716.xlsx*
   b. 39,084 points from 2-D rasters positioned at water table from file *UP-1_Tc99_rastervals_5m_spacing_120816.csv*
   c. 703 depth-discrete points from file WC_03_Tc99_DepthDiscrete_121416.xlsx
   d. 263 water well sample data points from file *WC_02_Well_Sample_Data_122216.xlsx*

2.2 Data Import into Leapfrog-Geo

1. The point data comprised of raster values, control points, depth-discrete data, and groundwater sample data (files *uranium_inputs_combined_04_122716.csv* and *tc99_inputs_combined_04_rev1_010917.csv* described previously) were imported into Leapfrog-Geo by right-clicking on the "Points" tab in the Project Tree and selecting "Import Points" (Points > Import Points).

2. The water table raster *2015wtbp_subset_to_UPlantAOI.tif* was imported into Leapfrog-Geo using the "Topographies" tab in the Project Tree (Topographies > New Topography > Import Elevation Grid). Setting this raster as the "Topography" enables it to be set as the upper boundary for the plume interpolation domain.

3. Shapefiles of the 2D contour lines developed in ECF-HANFORD-16-0061 (*U_2015_ctrs.shp* and *Tc-99_2015_ctrs.shp*) were imported into Leapfrog-Geo using the "GIS Data, Maps and Photos" tab in the Project Tree (GIS Data, Maps and Photos > Import Vector Data…). These were brought in to drape over the Topography layer (i.e., the water table) for visual reference. Beneath Topography in the view menu, GIS Data is selected by pulldown menu. Individual shapefiles can be displayed, or multiple items can be displayed by creating a "View." These options are contained within the pulldown menu.

2.3 3-D Interpolation in Leapfrog-Geo

1. Interpolation is carried out using the built-in interpolation utility in Leapfrog-Geo. The 3-D interpolation is accomplished using the proprietary FastRBF™ algorithm (Carr et al., 2001). The interpolation properties/parameters (Boundary, Trend, Value Transform, etc.) are accessed and adjusted by double-clicking on the Interpolant item of interest from the Project Tree.

2. Interpolant items for uranium and Tc-99 were initially created by selecting the appropriate input data set, setting the interpolant boundary to encapsulate the input data, and accepting default parameters. This is accessed by right-clicking on the "Interpolants" tab in the Project Tree (Interpolants > New Interpolant). Adjustments to the interpolant were made after the plume was created within Leapfrog.

3. Within the Boundaries tab of the interpolants for uranium and Tc-99, the option to use the Topography (the water table raster, in this case) as the upper boundary for the interpolation domain was selected. X and Y values reported below are in the Washington State Plane South (4602, meters, NAD83) projection.
   a. For uranium, the X values of the interpolation domain ranged from 565,400 m to 571,300 m, and the Y values of the interpolation domain ranged from 132,400 to 138,300 m. The bottom elevation of the interpolation domain was set to 40 m.
   b. For Tc-99, the X values of the interpolation domain ranged from 565,400 m to 571,500 m, and the Y values of the interpolation domain ranged from 132,400 m to 139,500 m. The bottom elevation of the interpolation domain was set to 40 m.

4. Parameters used within the Value Transform, Trend, Interpolant, and Outputs tab are reported in Section 5, Calculation. Isopleth values used for the creation of plume volumes were chosen to be consistent with those used in the 2-D interpolation of ECF-HANFORD-16-0061.

3 Assumptions and Inputs

Assumptions for the three-dimensional interpolations include the following:

1. The water table is static and adequately represented by the March 2015 water table raster.
2. Two-dimensional plume rasters developed in ECF-HANFORD-16-0061 apply to the upper surface of the water table.
3. The extents of the contaminant plumes are within the saturated portion of the unconfined units above the Ringold Lower Mud.
4. Uranium-238 concentration is a valid proxy value for uranium concentration and may be used in calculations with uranium data without any adjustment.

Input data for uranium are included digitally as file *uranium_inputs_combined_04_122716.csv*, and input data for Tc-99 are included digitally as file *tc99_inputs_combined_04_rev1_010917.csv*. These consist of depth-discrete data, groundwater sample data positioned according to the relation between the well screens and the 2015 water table, control points based on existing data points, and a large number of values converted from the 2-D rasters developed in ECF-HANFORD-16-0061 placed at elevations corresponding to the 2015 water table. Details on input data are provided in section 2.1 above.

4 Software Applications

Leapfrog-Geo, Microsoft Excel, and ArcGIS software programs were used for this calculation. These are CH2M HILL Plateau Remediation Company (CHPRC) approved software, managed and used in compliance with the requirements of PRC-PRO-IRM-309, *Controlled Software Management*. Leapfrog-Geo is approved calculation software with the approval documented in CHPRC-01755, *Leapfrog-Hydro and Leapfrog-Geo Acceptance Test Report: Leapfrog-Hydro Version 2.3.2 and Leapfrog-Geo Version 3.0.0*. Microsoft Excel®[4] was used as spreadsheet software. ArcGIS was used to extract values from two-dimensional rasters onto points, to place and determine projected coordinates of control points, and to manipulate shapefiles and their attributes.

4.1 Approved Software

Required descriptions for approved calculation software used in this calculation are provided below.

4.1.1 Description

Leapfrog-Geo

- Software Title:
  - Leapfrog-Geo
- Software Version:
  - 3.0.0
- Hanford Information System Inventory (HISI) Identification Number:
  - 3592 (Safety Software S3, graded to Level C)
- Authorized Workstation Type and Property Number:
  - INTERA-00710
- Authorized User:
  - C. Griffith
- CHPRC Software Control Documents:
  - CHPRC-01753, *Leapfrog-Hydro and Leapfrog-Geo Software Management Plan*
  - CHPRC-01754, *Leapfrog-Hydro and Leapfrog-Geo Software Test Plan*
  - CHPRC-01755, *Leapfrog-Hydro and Leapfrog-Geo Acceptance Test Report: Leapfrog-Hydro Version 2.3.2 and Leapfrog-Geo Version 3.0.0*

4.1.2 Statement of Valid Software Application

The preparers of this calculation attest that the software identified above and used for the calculations described in this calculation is appropriate for the application and used within the range of intended uses for which it was tested and accepted by CHPRC. Because Leapfrog-Geo is graded as Level C, use of this software is logged in the HISI. Accordingly, this ECF has been logged by the software owner in the HISI under identification number 3592.

[4] Excel is a registered trademark of Microsoft Corporation in the United States and in other countries.

5 Calculation

Three-dimensional interpolation was carried out for the two COIs uranium and Tc-99. The overall approach was kept consistent with the steps described in the methodology section of this ECF. Interpolation parameters were selected to match existing two-dimensional contours (ECF-HANFORD-16-0061) and site knowledge of project scientists. Table 1 shows the interpolation parameters used for the uranium plumes, and Table 2 shows the interpolation parameters used for the Tc-99 plumes.

Specific considerations for the interpolations are listed below:

1. Groundwater sample data from extraction wells were excluded from the interpolation for Tc-99. Relatively few groundwater samples were factored into the uranium plume, so this consideration was not a factor for that interpolant. This did not affect depth-discrete data. Specific to this calculation, groundwater sample data for the following wells were omitted from the analysis: 299-W11-96, 299-W6-15, 299-W14-22, and 299-W5-1. Other extraction wells were represented by depth-discrete data.

2. A depth-discrete Tc-99 measurement at well 299-W19-113 placed at elevation 115.386 m with a concentration of 58.2 pCi/L sampled in 2014 was omitted. This measurement also had a flag “B” in the original data set and was conspicuously lower than measurements at other depths at the same location. A more recent sample at a nearby point in well 299-W19-34A at elevation 113.34 m with a concentration of 947 pCi/L sampled on 2/5/2016 cast further doubt on the omitted measurement.

3. No distinction was made between how uranium and uranium-238 are treated in the interpolation.

Table 1. Interpolation parameters used for the uranium plumes in Leapfrog-Geo

Trend			
Directions		Ellipsoid Ratio	
Dip	0°	Maximum	3
Dip Azimuth	0°	Intermediate	1
Pitch	0°	Minimum	0.1
Value Transform			
Type	Log		
Pre-transform Clipping:		Pre-log Shift	-0.0752
Lower Bound	0.0762	Bin Count	50
Upper Bound	1468.2		
Interpolant			
Type	Spheroidal	Alpha	3
Sill	10,000	Nugget	0
Range	200	Accuracy	2
Drift	None		
Outputs			
Evaluation limits			
Minimum	0	Exact Clipping	Yes
Maximum	NA	Enclose	Intervals
Default Resolution:	5 m		
Intervals:	15 ug/L, 30 ug/L, 300 ug/L		

Table 2. Interpolation parameters used for the Tc-99 plumes in Leapfrog-Geo

Trend			
Directions		Ellipsoid Ratio	
Dip	0°	Maximum	3
Dip Azimuth	0°	Intermediate	1
Pitch	0°	Minimum	0.1
Value Transform			
Type	Log		
Pre-transform Clipping:		Pre-log Shift	~0.001
Lower Bound	0	Bin Count	50
Upper Bound	51,400		
Interpolant			
Type	Spheroidal	Alpha	3
Sill	10,000	Nugget	0
Range	200	Accuracy	3
Drift	None		
Outputs			
Evaluation limits			
Minimum	90	Exact Clipping	Yes
Maximum	NA	Enclose	Intervals
Default Resolution:	5 m		
Intervals:	500 pCi/L, 900 pCi/L, 9000 pCi/L		

6 Results / Conclusions

Figure 6 shows the three-dimensional plumes for uranium, and Figure 7 shows the three-dimensional plumes for Tc-99 in the 200 West Area. These figures show the plumes as three-dimensional volumes and input data points with values at or above 15 ug/L for uranium and 500 pCi/L for Tc-99, excepting the numerous input data points derived from the 2-D rasters. Contour line shapefiles for the 2-D rasters are draped on the water table surface in the figures for reference. The Leapfrog-Geo 3.0.0 project file for these plumes is stored on EMMA. Leapfrog Viewer 4.6 files for the two plumes are also stored on EMMA. These files are opened with the free Leapfrog Viewer, which is available at http://www.leapfrog3d.com/products/leapfrog-viewer.

7 References

Aero-Metric LiDAR, 2008, RCCC-Hanford Battelle/PNNL/DOE, Digital Orthophotography and LiDAR Surveys Photogrammetric Report, prepared by Aero-Metric, Seattle, Washington.

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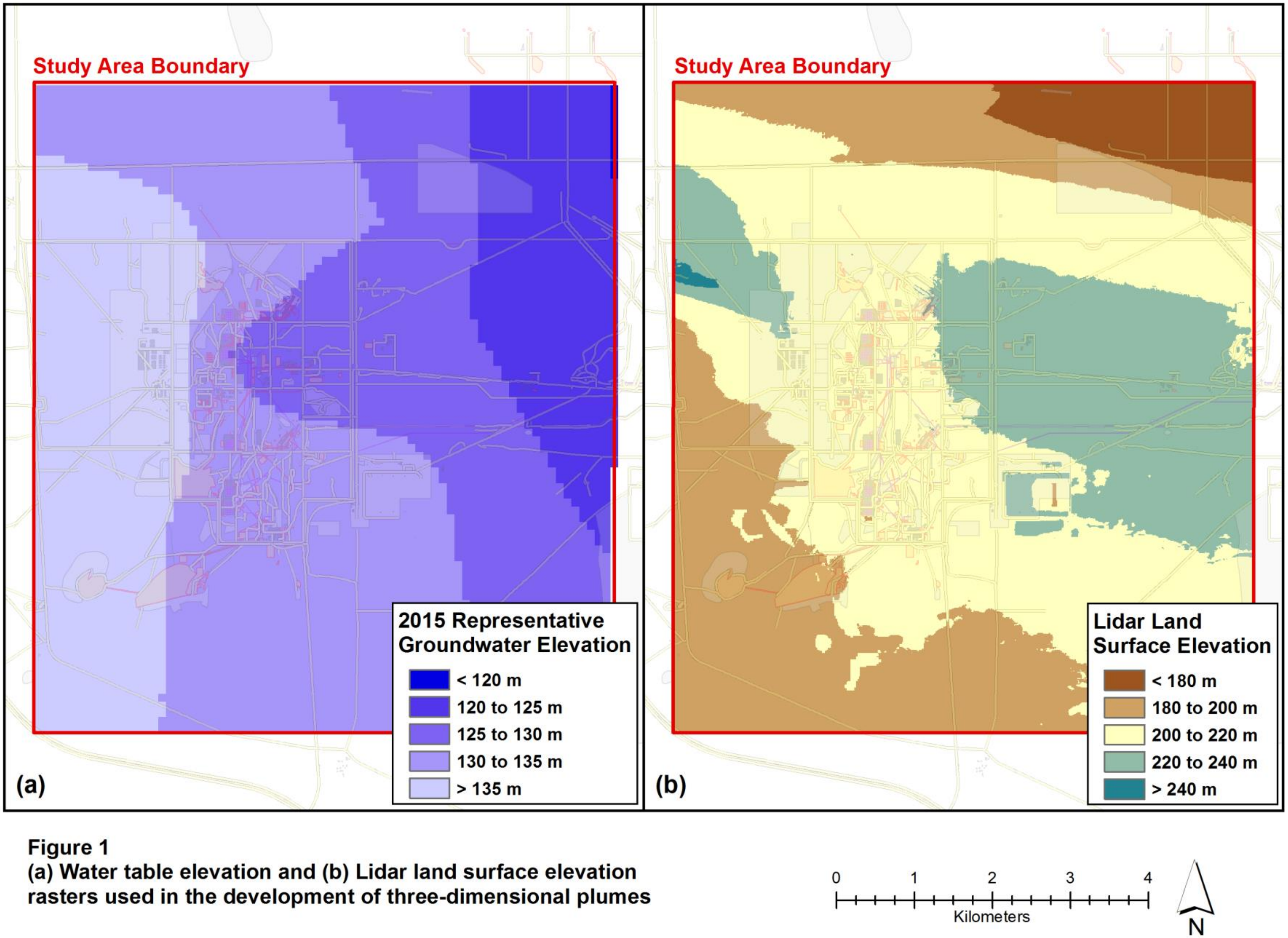

Figure 1
(a) Water table elevation and (b) Lidar land surface elevation rasters used in the development of three-dimensional plumes

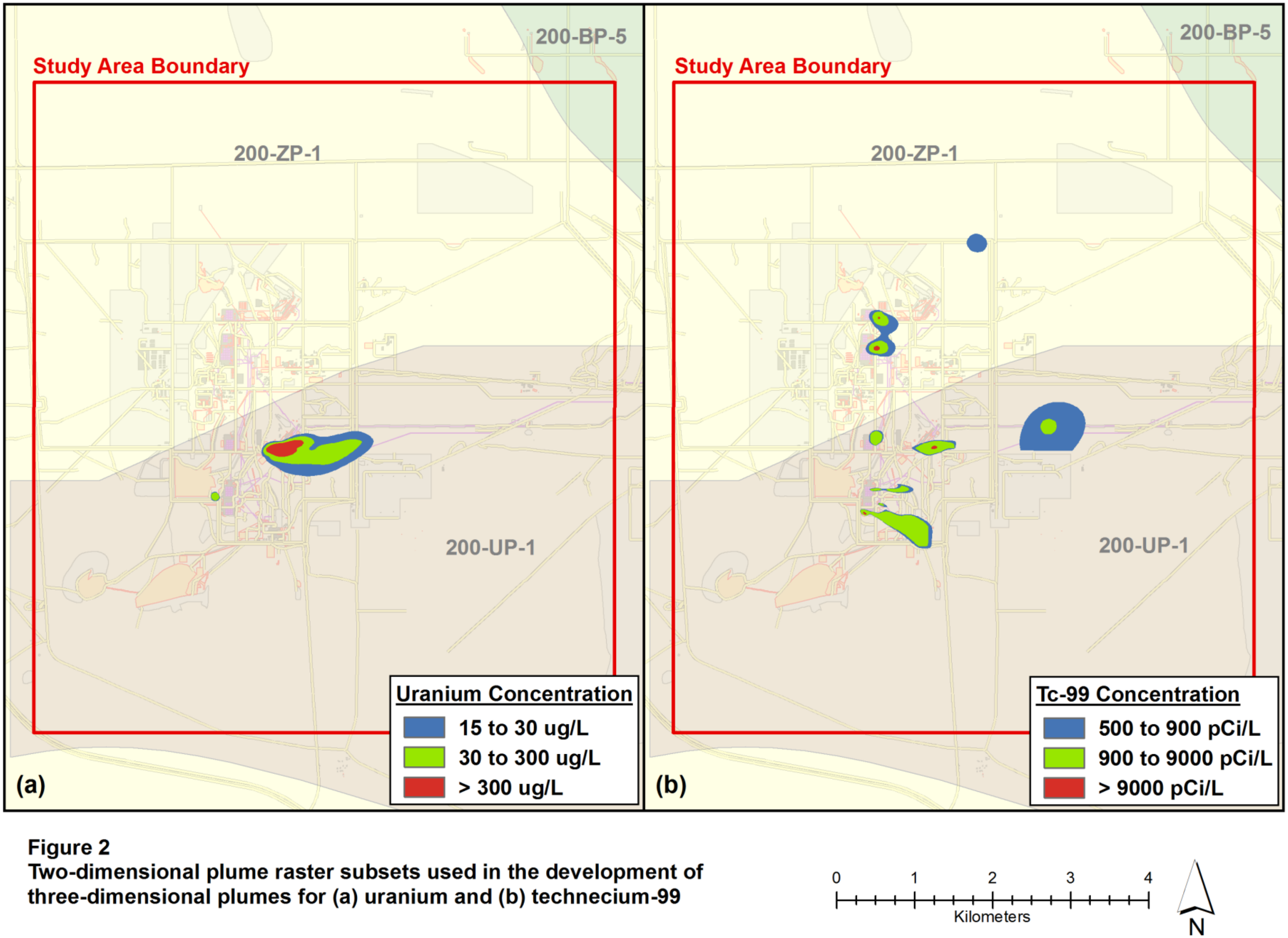

Figure 2
Two-dimensional plume raster subsets used in the development of three-dimensional plumes for (a) uranium and (b) technecium-99

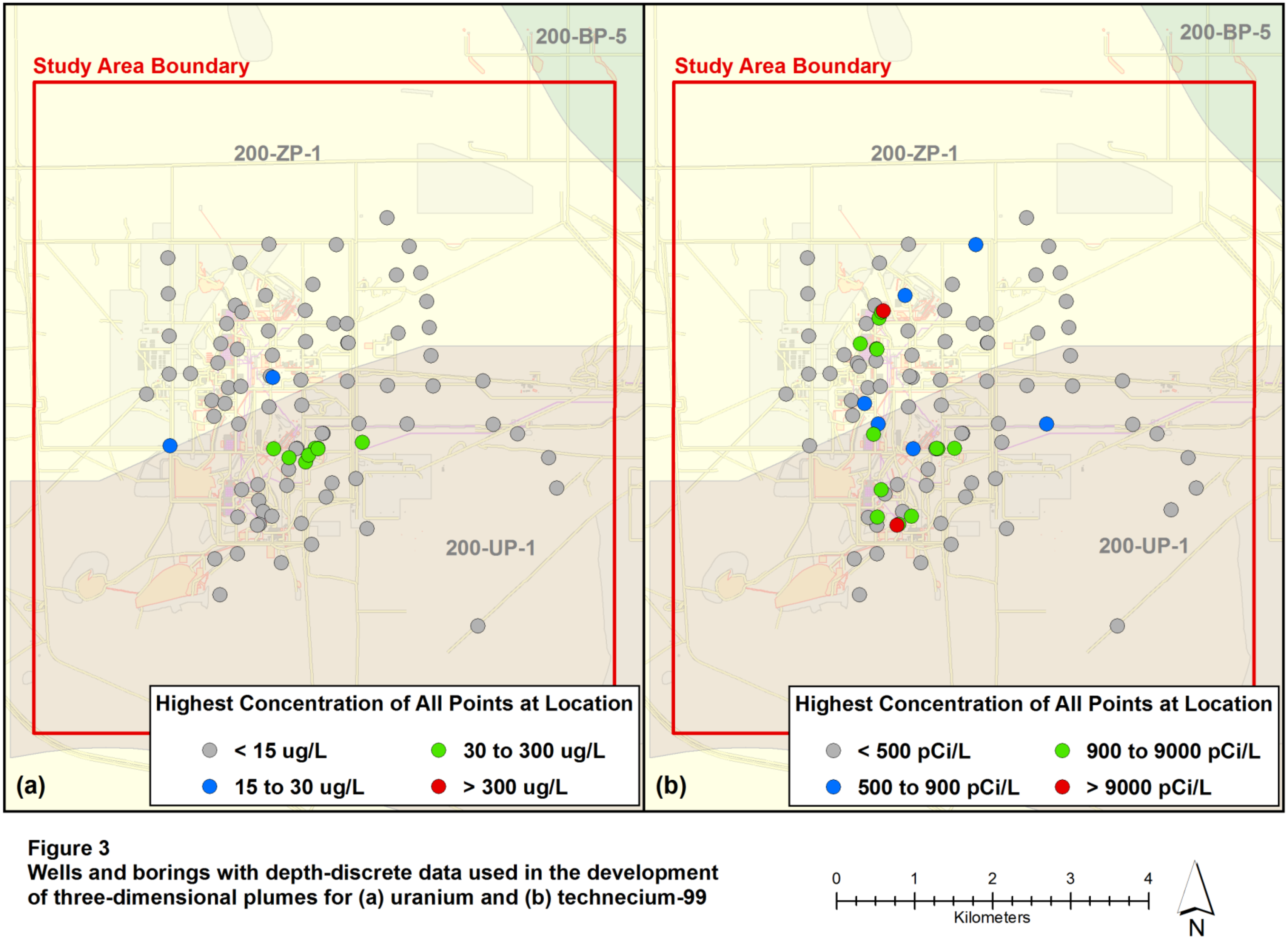

Figure 3
Wells and borings with depth-discrete data used in the development of three-dimensional plumes for (a) uranium and (b) technecium-99

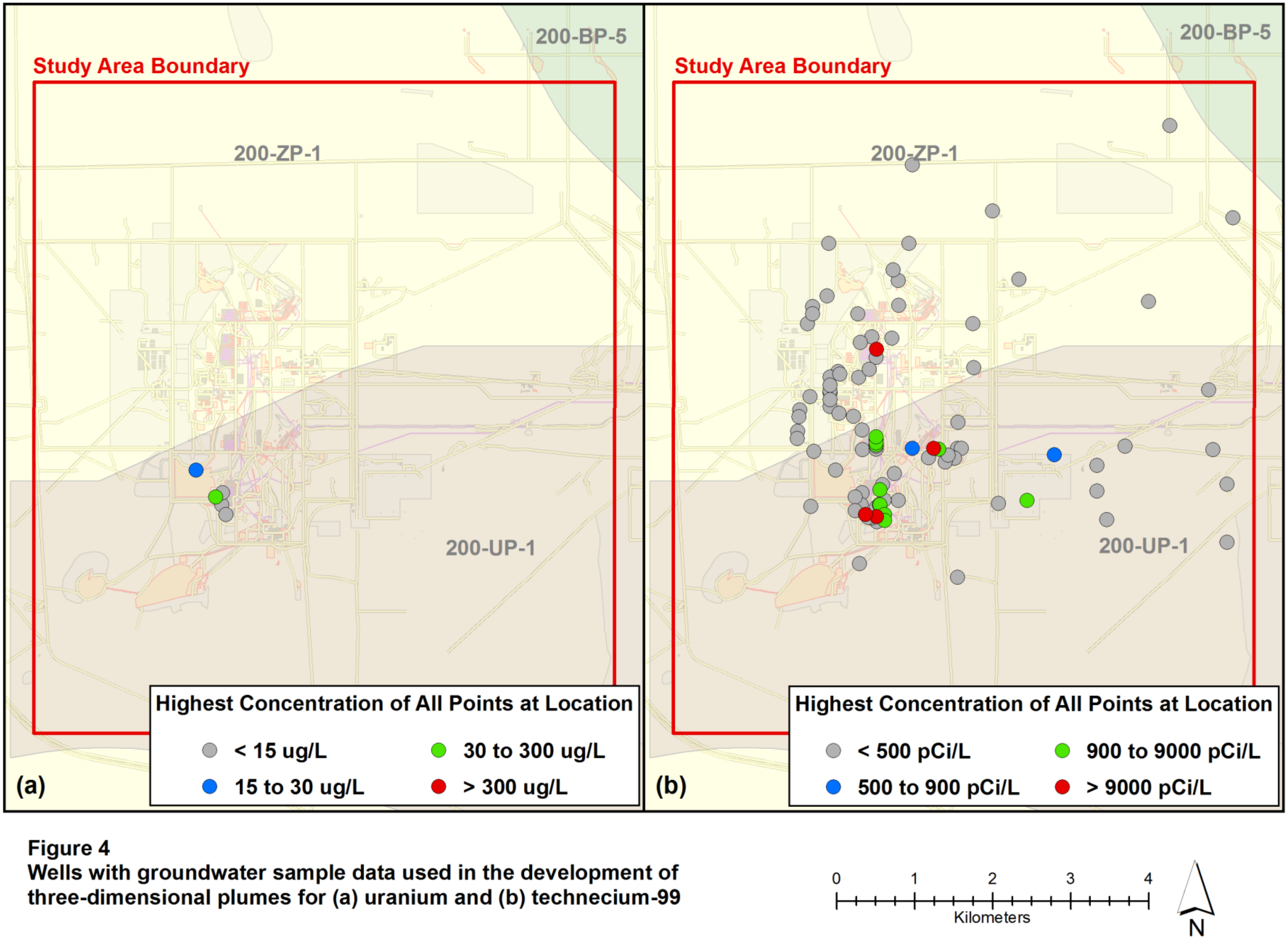

Figure 4
Wells with groundwater sample data used in the development of three-dimensional plumes for (a) uranium and (b) technecium-99

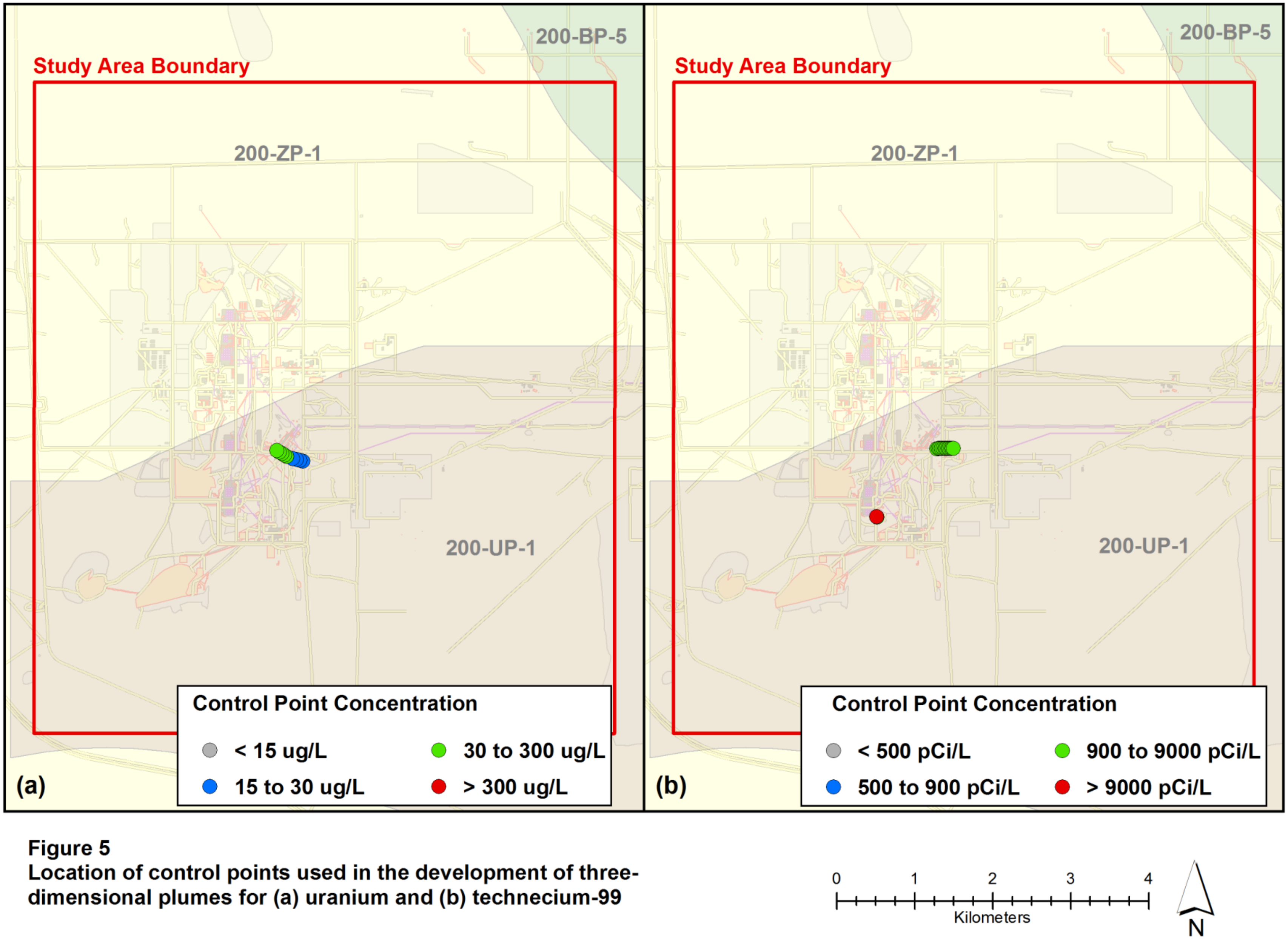

Figure 5
Location of control points used in the development of three-dimensional plumes for (a) uranium and (b) technecium-99

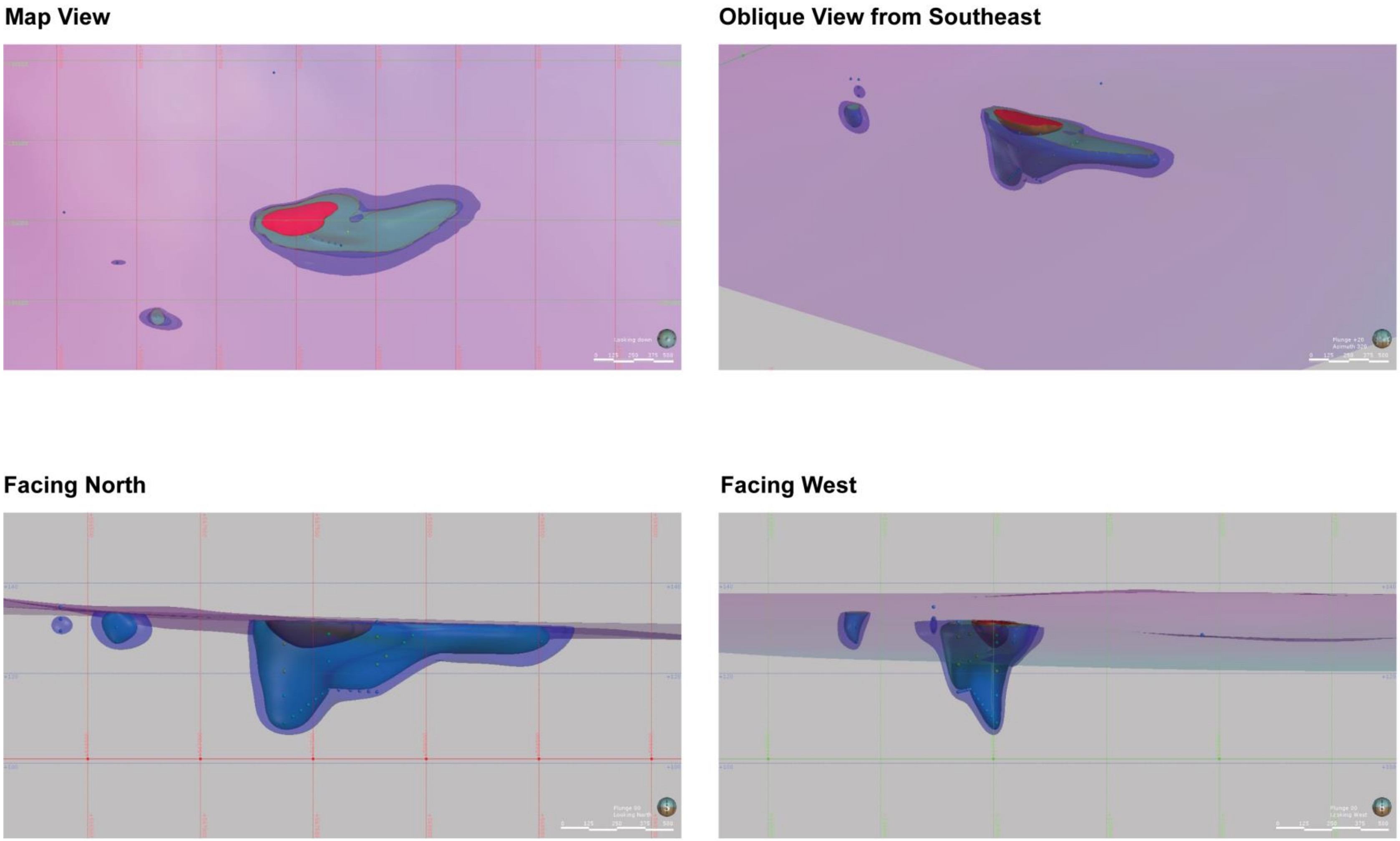

Figure 6
Interpolated uranium plumes and input data points with concentrations of 15 ug/L or greater

Colored volumes indicate concentration intervals:
Blue: 15 to 30 ug/L
Green: 30 to 300 ug/L
Red: > 300 ug/L

The upper surface of the plumes is the 2015 water table.
Input data points derived from 2-D rasters are not shown.

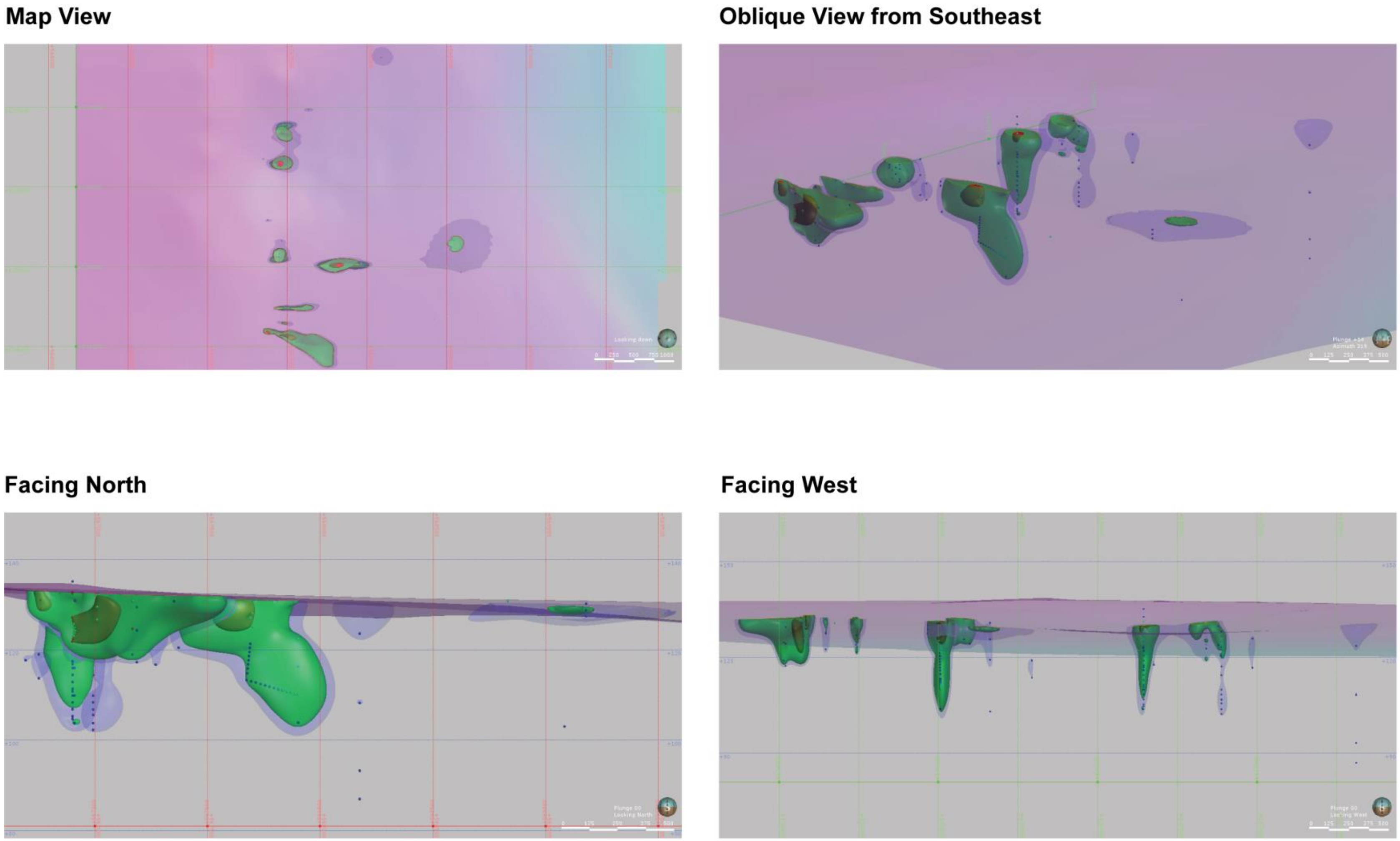

Figure 7
Interpolated Tc-99 plumes and input data points with concentrations of 500 pCi/L or greater

Colored volumes indicate concentration intervals:
Blue: 500 to 900 pCi/L
Green: 900 to 9000 pCi/L
Red: > 9000 pCi/L

The upper surface of the plumes is the 2015 water table.
Input data points derived from 2-D rasters are not shown.